Power Quality Improvement and Mitigation of Harmonics for Grid Integrated Wind Energy System Using STATCOM

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***Abstract*— Wind power is one of the optimistic source of energy generation among all the renewable energy sources. Hence for effectively exploiting wind energy sources it must be connected to electric grid. Wind power inculation into grid affects power quality because of its fluctuating nature. The concerned power quality issues are voltage sag, voltage swell, active power, flicker, reactive power, harmonics, voltage interruption and power quality depends upon performance of switching devices. This paper recommends a control scheme based on instantaneous SRF theory for compensating the reactive power requirement of a three phase grid connected wind energy generating system along with mitigation of harmonics produced by non linear load connected at PCC using STATCOM. To overcome the power quality issues of grid connected wind energy generating system, the STATCOM control scheme with non linear load is simulated using MATLAB/SIMULINK. The results of this sustainable and renewable model are to meet the power demand and for promoting green energy systems.**

Index Terms— Power quality, wind energy generating system (WEGS), STATCOM, active power, reactive power, voltage regulation.

I. INTRODUCTION

Now a days energy demand is increasing rapidly, due to the growth in population and economic development in the world leading to increase in environmental impact on conventional plants. Hence renewable energy resources must be employed in order to meet the energy demand and have communal development and prolong growth [1].In recent years, among the other renewable energy sources, wind energy is gaining ever increasing attention as a clean, safe and economical resource. Thus to exploit wind power effectively its grid connection is necessary so as to realize its potential to significantly mitigate present day problems like energy demand along with atmospheric pollution [2].But amalgamation of wind power to grid introduces power quality issues, which predominantly consist of voltage regulation and reactive power compensation. The power quality is a crucial customer-focused measure and is of prominent importance to the wind turbine. Wind turbine produces a continuously variable output power during its normal operation. Voltage sag, swell, flickers, harmonics etc are the power quality issues which are more harmful to wind generation, transmission and distribution network i.e. for grid. In wind power based generation, mostly induction generators are used because of its cost effectiveness and robustness. Induction generators draw reactive power from the grid for magnetization to which they are connected. The active power generated by induction generated is varied due to fluctuating nature of wind and this variation can prominently affect the absorbed reactive power and terminal voltage of induction generator. Thus in order to have proper control over the active power production under normal operation, a control scheme in wind energy generation system is required. For improving the power quality of wind generating system a STSTCOM based control technology has been proposed. A STSTCOM is connected at common coupling point (PCC) along with battery energy storage system (BESS) to make the source current harmonic free and to improve the system performance. The proposed STATCOM along with hysteresis current control scheme for grid connected wind energy generation for improving the power quality has following objectives [3].

- Maintain the source side power factor at unity.
- Support the reactive power to wind turbine and non-linear load from STATCOM.
- For fast dynamic response bang-bang controller is implemented in STATCOM.
- Minimize the THD percentage at the PCC waveform.

The paper is presented as follows: Section II introduces about the power quality issues and its consequences on grid. Section III describes the topology for power quality improvement. Sections IV, V, VI describe the control scheme; discuss test system output waveform/results, conclusion respectively.

II. POWER QUALITY ISSUES AND ITS CONSEQUENCES

The ideal power supply system is nothing but the ideal power quality means to supply electric energy with ideal and constant supply frequency with pure sinusoidal waveform of a described voltage with minimum disturbances. Power quality issues are getting increasingly important day by day to utility grid and end user consumers. The various power quality problems are voltage sag, swell, interruption, voltage

unbalance, flicker, and harmonics etc which are discussed briefly.

A. Voltage Sag

It is defined as decrease in voltage between 10 to 90% of its nominal rms voltage at the rated power frequency i.e. 50Hz. Voltage sag consequences are tripping of motor or causes its controller to malfunction, namely programmable logic controller, microprocessor based control system, adjustable speed drives that may lead to a process stoppage [4].

B. Voltage Swell

Voltage swell is an increase in RMS voltage in range of 10 % to 80% for duration greater than half cycle and less than 1 minute. A swell can occur due to a single line-to-ground fault on the system which can result temporary voltage rise on the other unfaulted phases. Swells can also be caused by switching off a large load or switching on a large capacitor bank [4].

C. Voltage Interruption

Voltage interruption is nothing but the supply voltage goes close to zero that means lower than 10% of its nominal voltage. Interruptions can results the power system faults, equipment failure, and control system malfunction.

D. Voltage Unbalance

Voltage imbalance is deviation in the magnitude and phase of one or more of the phases, of a three phase supply, with respect to the magnitude of the other phase and the normal phase angle (120deg). Voltage imbalance can cause temperature rise in motors and can even cause a large motor to trip [4].

E. Flicker

Flicker comes due frequent on-off or switching regularly of large loads connected to grid. It results rapid variation in voltage and changing brightness of incandescent and fluorescent lamps at consumer end. Flicker has adverse effects on human health due to the high frequency flickering of light bulbs, fluorescent tubes or television screen can cause stress on the eyes resulting in headache.

F. Harmonics

It is a sinusoidal component of a periodic wave having a frequency that is an integral multiple of the fundamental frequency. A non-linear element in power systems such as power electronic devices, static power converters, arc discharge devices etc creates harmonics in system. Harmonics cause communication interference, heating, and malfunction of equipments.

The voltage variation, sag, swell, harmonics causes malfunctioning of electronics equipments namely microprocessor based system, programmable logic controller, adjustable speed drives etc. Due to all this problems it may cause tripping of contractors, protection devices, also stoppage of sensitive equipments like computer, programmable logic control system and may be damage the sensitive equipments. Due to all this problems the whole system will be derated.

III. TOPOLOGY FOR POWER QUALITY IMPROVEMENT

The STATCOM with capacitance at DC side is a three phase voltage source inverter. The basic principle of STATCOM installed in power system is to generate controllable ac voltage source by a VSI connected to dc capacitor. Here the shunt connected STATCOM is operated in current control mode and is connected with wind turbine induction generator and non-linear load at the point of common coupling (PCC) in the grid system. The current controlled voltage source inverter based STATCOM injects the current into the grid in such a way that the source current (grid current) are harmonic free and they are in phase-angle with respect to source voltage. The injected current will cancel out there active part and harmonic part of the induction generator current and load current, thus it improves the system power quality. To achieve these goals, the grid voltages are sensed by sensors and are synchronized for generating the current [1]. The proposed grid connected system with battery energy storage system with STATCOM and wind energy generation system is implemented for power quality improvement at the point of common coupling (PCC) is shown in fig 1. The grid integrated system in Fig. 1, includes wind energy generation system with non linear load connected and battery energy storage system with STATCOM.

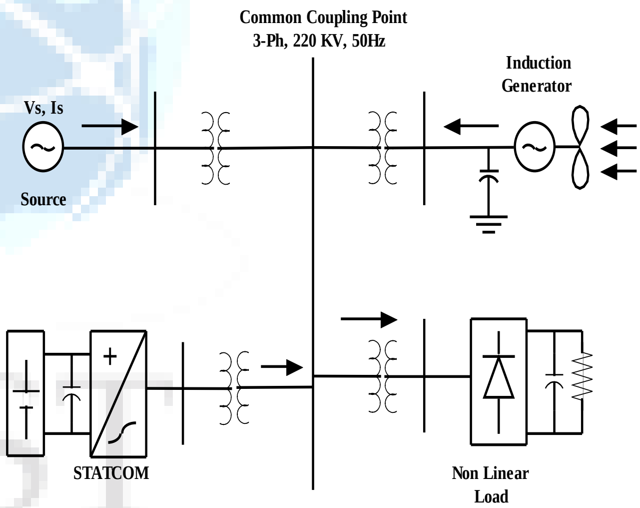

Fig. 1. Grid Connected Wind Turbine with non linear load & STATCOM for PQ improvement.

A. Wind Energy Generating System

The wind energy is not a constant energy source. Its output is varies according to variation of wind, the electricity is produced by using the power of wind to rotate the induction generator. The wind turbine generation system is depending upon the constant speed with variable pitch angle. In this proposed system induction generator is used in wind turbine because of its simple construction and working. IG does not require the separate field circuit for magnetization also it can bare the variable and constant loads and it has inbuilt protection of short circuit. The wind turbine kinetic energy extracted from wind is given as "(1)".

$$P_{wind} = 0.5\rho AV^{3}{}_{wind} \quad (1)$$

Where P_{wind} is power contained in wind (Watts), ρ is the air density (kg/m), A is the area of turbine blade (m), V_{wind} is the

wind speed in mtr/s. The above equation shows that the wind energy is directly proportional to the cube of actual wind speed. There is large effect on output power of wind for small change in speed.

The equation (1) shows the total power available in wind turbine, but it is not possible to extract all kinetic energy, hence the power transferred to the wind farm rotar is reduced by *Cp* power coefficient and it given as "(2)".

$$P_{mech} = C_P P_{wind} \tag{2}$$

Where *C*p is the power coefficient, it depends on operating condition and type of wind turbine connected.

The Cp coefficient is a function of tip speed ratio (TSR) i.e. λ and pitch angle θ. Thus the actual mechanical power developed in wind turbine is presented in "(3)".

$$P_{wind} = 0.5\rho\pi R^2 V^3{}_{wind} \tag{3}$$

Where R (m) is the radius of the wind turbine blade.

B. BESS System

For the purpose of voltage regulation, battery energy storage system is used as an energy storage element. To stabilize the grid system, the STATCOM rapidly injects or absorbs reactive power. Thus BESS is best suited in STATCOM because it can naturally maintain dc capacitor voltage. The battery for energy storage is connected in parallel to the dc capacitor of STATCOM. BESS is used to level the power fluctuation that occurs in system by charging and discharging operation [5].

C. System Operation

A shunt connected STATCOM consists of a two-level Voltage Source Converter (VSC), a DC energy storage device connected to the distribution network through the coupling transformer. The DC voltage across the storage device is converted into a set of three-phase AC output voltages which are in phase by VSC and through the reactance of the coupling transformer these voltages are coupled to the AC system. In order to have effective control of active and reactive power exchange between STATCOM and ac system, suitable adjustment of phase and magnitude of STATCOM output voltages is needed. Thus power quality norms in the grid system are maintained by varying the STATCOM compensator output according to the current control strategy included in control scheme and this defines functional operation of STATCOM compensator in power system.

The STATCOM with battery energy storage system (BESS) is integrated in shunt with wind turbine induction generator and three phase non linear load at the point of common coupling (PCC). This proposed configuration supports the reactive power to the non linear load and wind turbine to improve the system performance of grid. The actual system operational scheme is shown in fig. 2.

IV. CONTROL SCHEME

The control scheme approach is based on injecting the currents into the grid using ―bang-bang controller. The controller uses a hysteresis current controlled technique. Hysteresis current control is a technique of controlling a VSI so that output current is generated which follows a reference

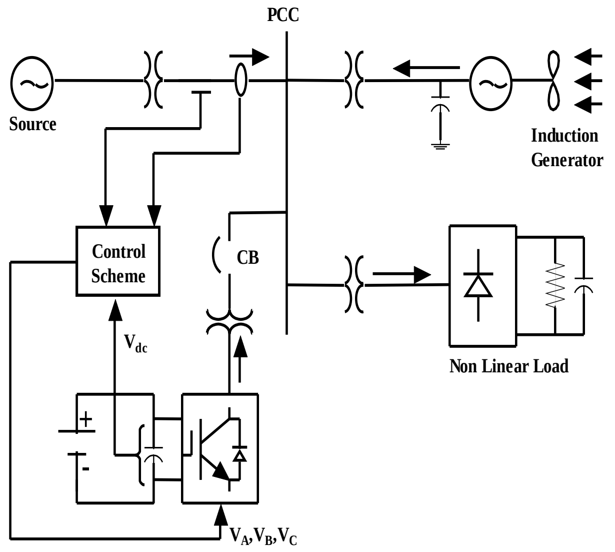

Fig. 2. Block Diagram of System Operational Scheme

current waveform. With hysteresis control limit bands are set on either side of a signal representing the desired output waveform. Controller keeps the control system variable. The switching signals generation for STATCOM control scheme is shown in Fig. 3.

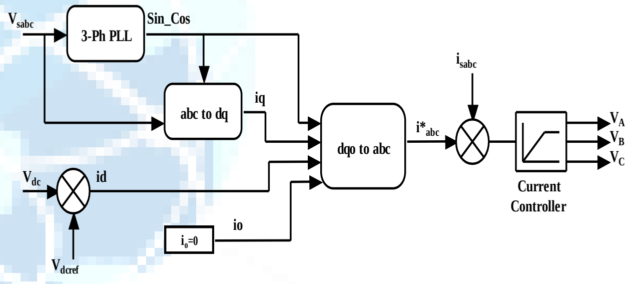

Fig. 3. Control Scheme For STATCOM

The control system requires the measurement of DC voltage, three phase voltages, and source current with the help of sensors. The current controller receives an input of actual current of system and reference current generated from SRF theory. Both the inputs are subtracted to get the output signals for STATCOM operation [6].

A. Synchronous Rotating Frame (SRF) Theory

STATCOM is used to eliminate the harmonics parts of source current and maintain the unity power factor at PCC. Also STATCOM provides reactive power to the non linear load and wind turbine as needed. Therefore the source provides real power only, load balancing is achieved by making the source reference current balanced. The reference for the source current vector is first computed and the desired compensator currents are obtained as the difference between the load and the source (reference) currents. The determination of reference source current vector is based on Synchronous Reference Frame (SRF) theory [7].

The synchronous reference theory is based on the transformation of three phase variables (a,b,c) of stationary reference frame to synchronous reference frame variables (d,q,0) whose direct (d) and quadrature (q) axes rotate in space at the synchronous speed ω_e. ω_e is the angular electrical speed of the rotating magnetic field of the three phase supply, given by ω_e=2πfs, where fs is the frequency of the supply. If θ

is the transformation angle, then the current transformation from abc to d-q-0 frame is defined as,

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

The quadrature axis component (i_q) is derived from three phase PLL block & abc to dq block. Similarly the direct axis component (i_d) is derived from dc voltage (V_{dc}) and reference voltage V_{dcref}. The i_o component is kept zero for calculating reference currents. All this i_q, i_d & i_o components are again transformed into abc component for reference current [8].

B. Bang-Bang Current Controller

In the current control scheme, bang-bang current controller is implemented. This controller uses a hysteresis current controlled technique. A hysteresis pulse width modulated (PWM) current controller is employed over the reference currents (i^*a, i^*b and i^*c) generated as per the SRF theory and sensed supply currents (isa, isb and isc) with current sensors to generate the switching signals for IGBT. The hysteresis controller controls the STATCOM output current within the permissible hysteresis band. Thus the ON/OFF switching signals for IGBT of STATCOM are generated from hysteresis controller [9].

The main aim of this controller is to bring the value of variable y to its desired set point y_{set} and keep it at its position. The input to the controller is the error term e:

$$e = y - y_{set}$$

If e > HB (Hysteresis Band) output v=1

If e < HB (Hysteresis Band) output v=0

The hysteresis band of 0.5 is defined for the generation of switching signals from reference current and the switching signals are simulated within this band. To improve the current quality in the system, narrow hysteresis band is chosen. The system voltage and the coupling transformer impedance play a key role in deciding the current band. The switching function V_A for phase "a" is expressed as

$$\text{When } i_a < (i^*_a - HB) \rightarrow V_A = 0$$

$$\text{When } i_a > (i^*_a - HB) \rightarrow V_A = 1$$

Where HB is a hysteresis current-band and it is taken as 0.5, correspondingly the switching signals V_B, V_C can be derived for phase's b and c respectively [10].

V. Simulink Modeling Of SRF Theory Based STATCOM Control Scheme For Grid Integrated Wind Energy Generating System

The proposed STATCOM control scheme with wind farm and non linear load is simulated using MATLAB SIMULINK in power system blocks. Fig.4 shows the MATLAB simulation model along with STATCOM. The power circuit and control circuit in incorporated in simulink block sets. The three phase AC source is connected to grid along with three phase non linear load with induction generator wind turbine. The STATCOM is connected in shunt at PCC and it consists of SRF theory with hysteresis control technique for pulse generation for IGBT and DC capacitor connected DC bus. Here the system performance of uncompensated system and compensated system is presented.

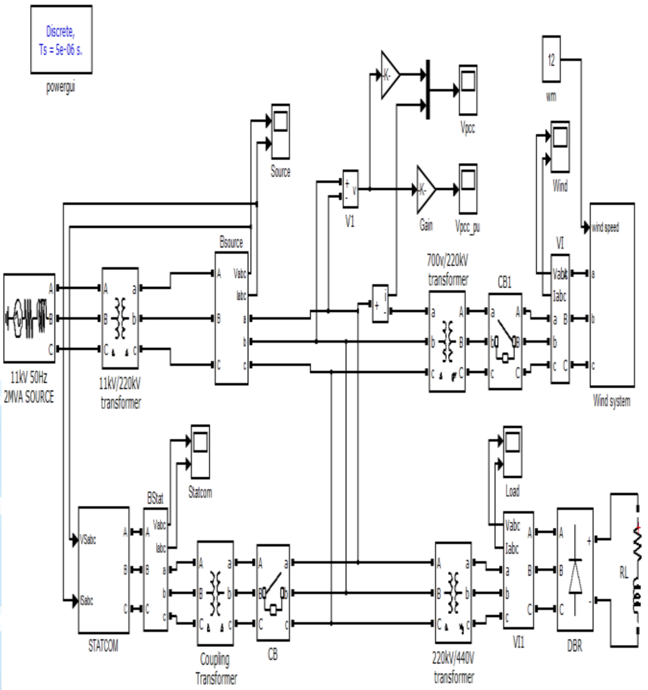

Fig. 4. MATLAB model for Grid connected wind turbine with STATCOM

A. Wind farm connected to grid without STATCOM

Here, the wind turbine is linked to the grid which is feeding to three phase non linear load. The current and voltage waveforms of source at PCC are depicted in Fig 5. From the Fig 5, it is observed that the source current and voltage waveforms are distorted due to connection of wind generating system with the grid. At 0 sec only three phase source is feeding to the non linear load. At t=0.1sec wind farm is connected to the grid. When induction generator is connected to grid it starts to draws the reactive power from grid for magnetization Non linear load connected distorts the source current and increases the harmonics. Due to this the voltage and current waveforms are differ from sine wave also source voltage and current are not in phase as shown in Fig.5. Hence the power factor of system is not unity. Fig 6 shows the FFT analysis for grid integrated wind generating system without STATCOM. It shows that the total harmonic distortion for the current at PCC waveform without STATCOM is 8.74%.

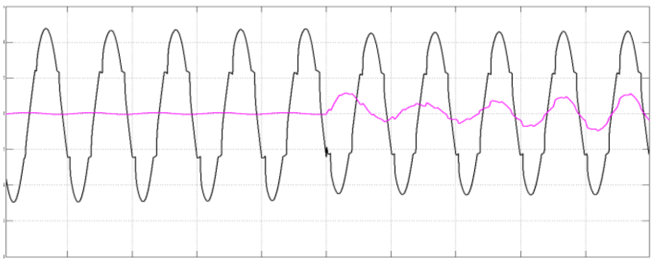

Fig. 5. Voltage and Current at PCC

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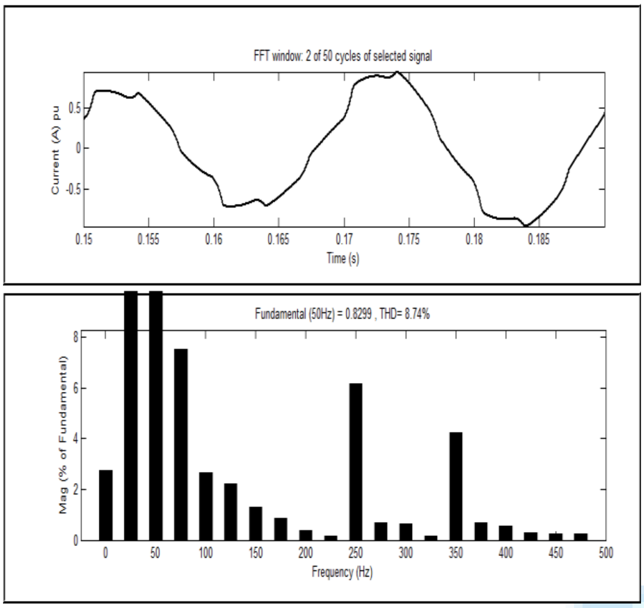

Fig. 6. FFT of Source Current without STATCOM

B. *Wind farm connected to grid with STATCOM*

The system performance is analyzed with and without STATCOM. The source current and voltage are affected due to connection of wind turbine and non linear load, thus the wave shape is affected at source side and PCC also. The STATCOM is connected to the grid at t = 0.2s.The source voltage and current waveforms for this case at PCC are shown in Fig 7. It is observed from Fig 7 that when the STATCOM is switched ON at 0.2s, it starts to reduce the reactive demand as well as harmonics presented in system. Also at PCC the source voltage and current are in phase this shows that the power factor is maintained at unity. Along with source current the STATCOM reduces the harmonics present in source voltage. Fig 8 shows the FFT analysis for grid integrated wind turbine system with battery energy storage system STATCOM. It shows that the harmonic distortion for the source current waveform with STATCOM is 3.15% which is within the limits as per the standards. Thus the performance of the controller designed for STATCOM is satisfactory as it helps to mitigate the source current harmonics introduced by the wind generating systems. Thus the power quality improvement is observed at point of common coupling, when the STATCOM is in ON condition.

The DC link voltage maintain the reactive power and active power also it regulates the source current in the grid system, because of that the DC link voltage is maintained constant across the capacitor as shown in Fig. 9.

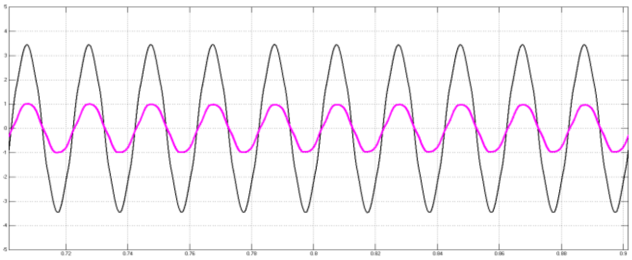

Fig. 7. Voltage & Current at PCC

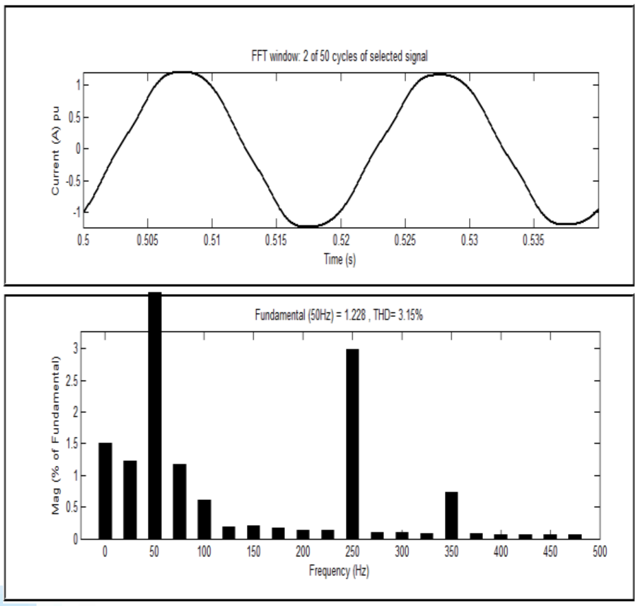

Fig. 8. FFT of Source Current with STATCOM

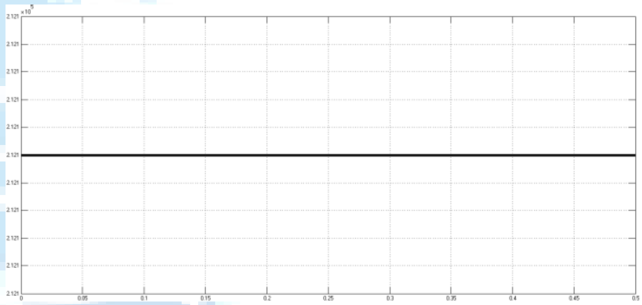

Fig. 9. DC Link Voltage

VI. CONCLUSION

This paper presents the STATCOM- based control scheme, using instantaneous SRF theory for compensating the reactive power requirement of a three phase grid connected wind energy generating system and mitigation of source current harmonics produced by non linear load and wind turbine connected at PCC. The power quality issues arising due to the connection of wind generation system to the gird and its consequences on the consumer and electric grid are presented briefly. The STATCOM based control scheme for improving the power quality is simulated in MATLAB/SIMULINK. In this paper controller based on hysteresis current control scheme is incorporated for the STATCOM in order to have fast dynamic response and its potency in curtailing the harmonics in the source current waveform was studied by examining the waveform before and after STATCOM operation. Due to connection of STATCOM harmonic part of source current is cancel out and source voltage and current is maintained in phase i.e. unity power factor is maintained and support the reactive power demand. It observed from the simulation results that the THD in the source current waveform is reduced from 8.74% to 3.15% after the connection of STATCOM. Thus the coherent wind generation system and STATCOM with BESS have shown the exceptional performance and hence this scheme can be practically implemented to meet the subsequent power demand.

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